

# Interfacial Force Microscopy: New Tools for Nanomechanics

## The Instrument

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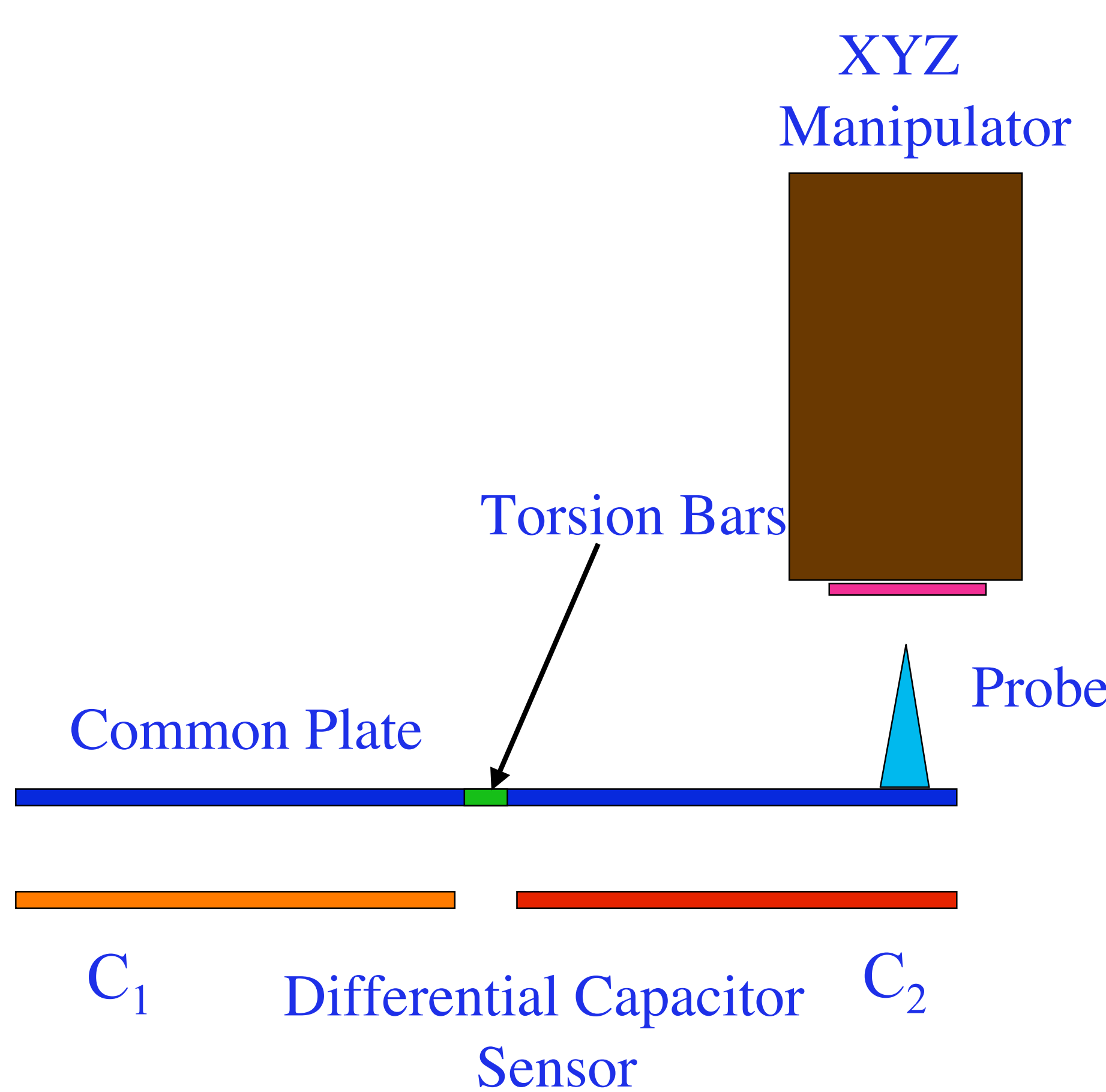
## Areas of Application

### Objective

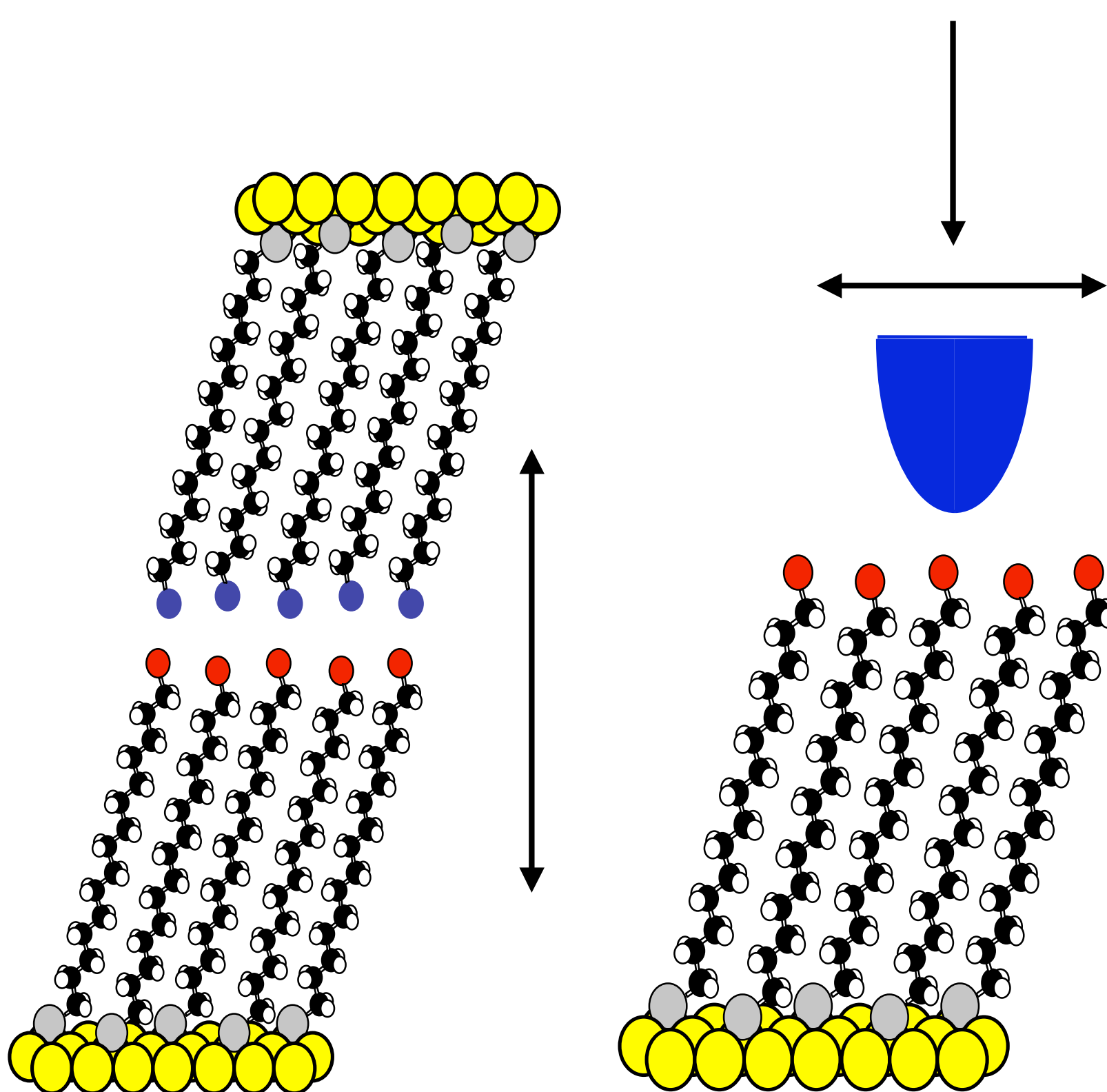
- Develop a scanning force-probe technique centered around a mechanically stable and quantitative force sensor

### Approach

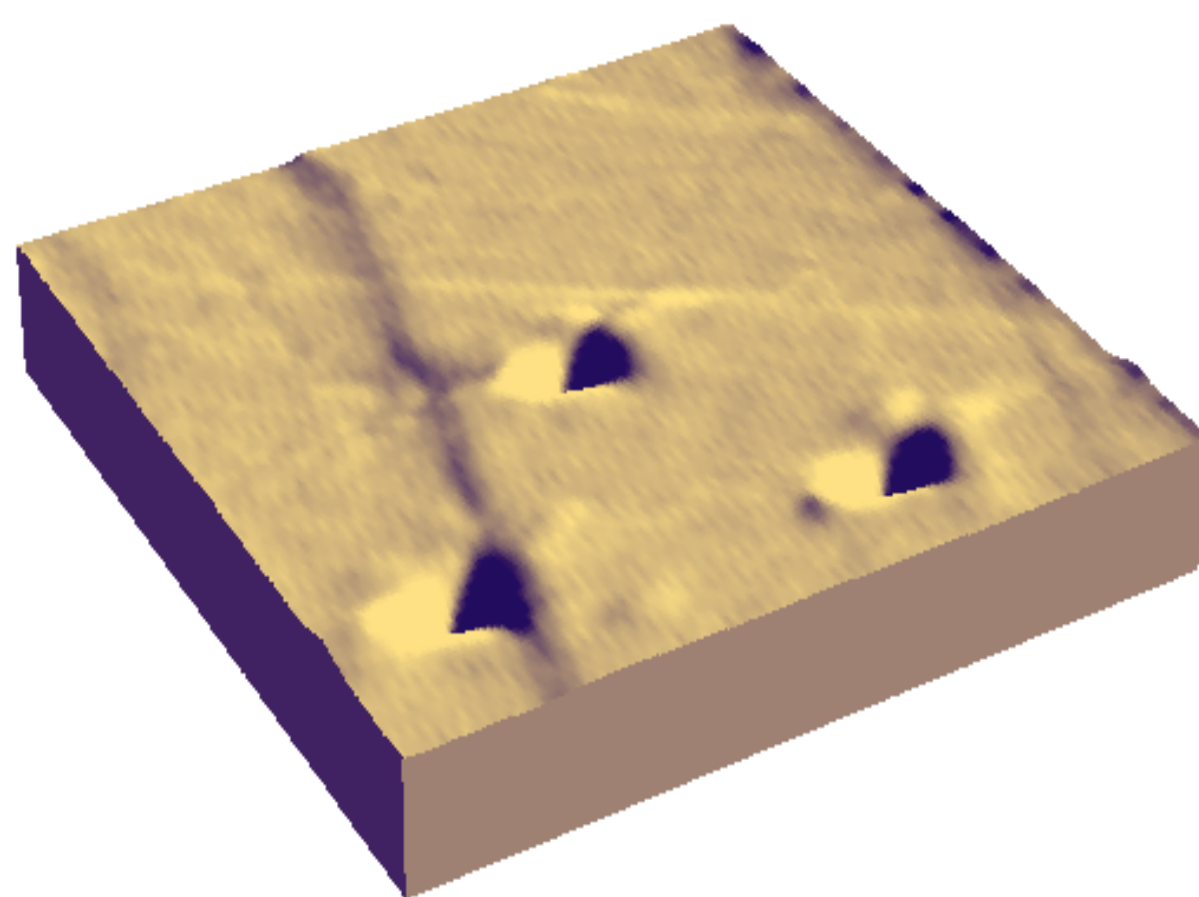
- Design a self balancing, force-feedback sensor with differential capacitance displacement detection and self balancing by electrostatic feedback



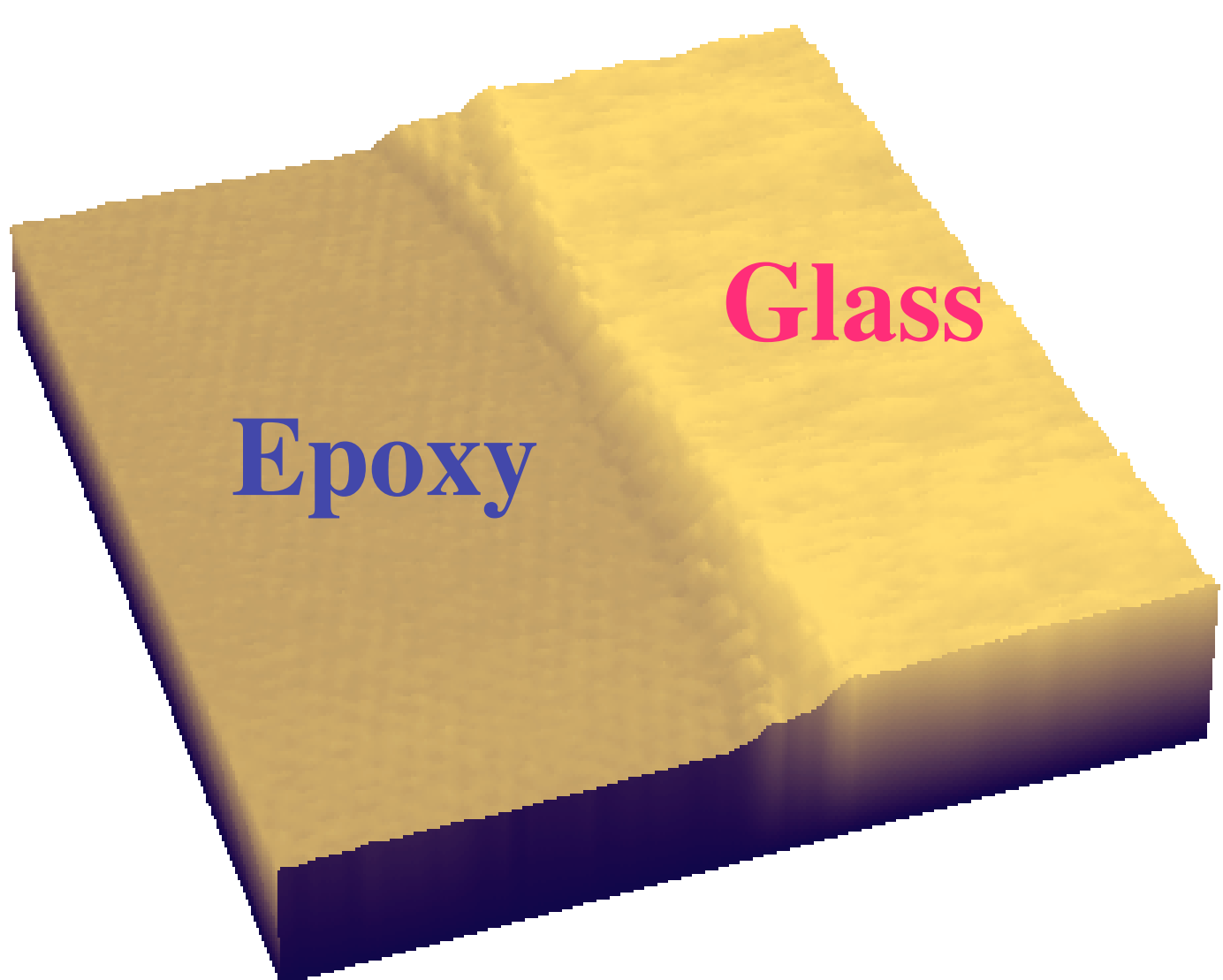
### Molecular Level Adhesion and Friction



### Nanoindentation



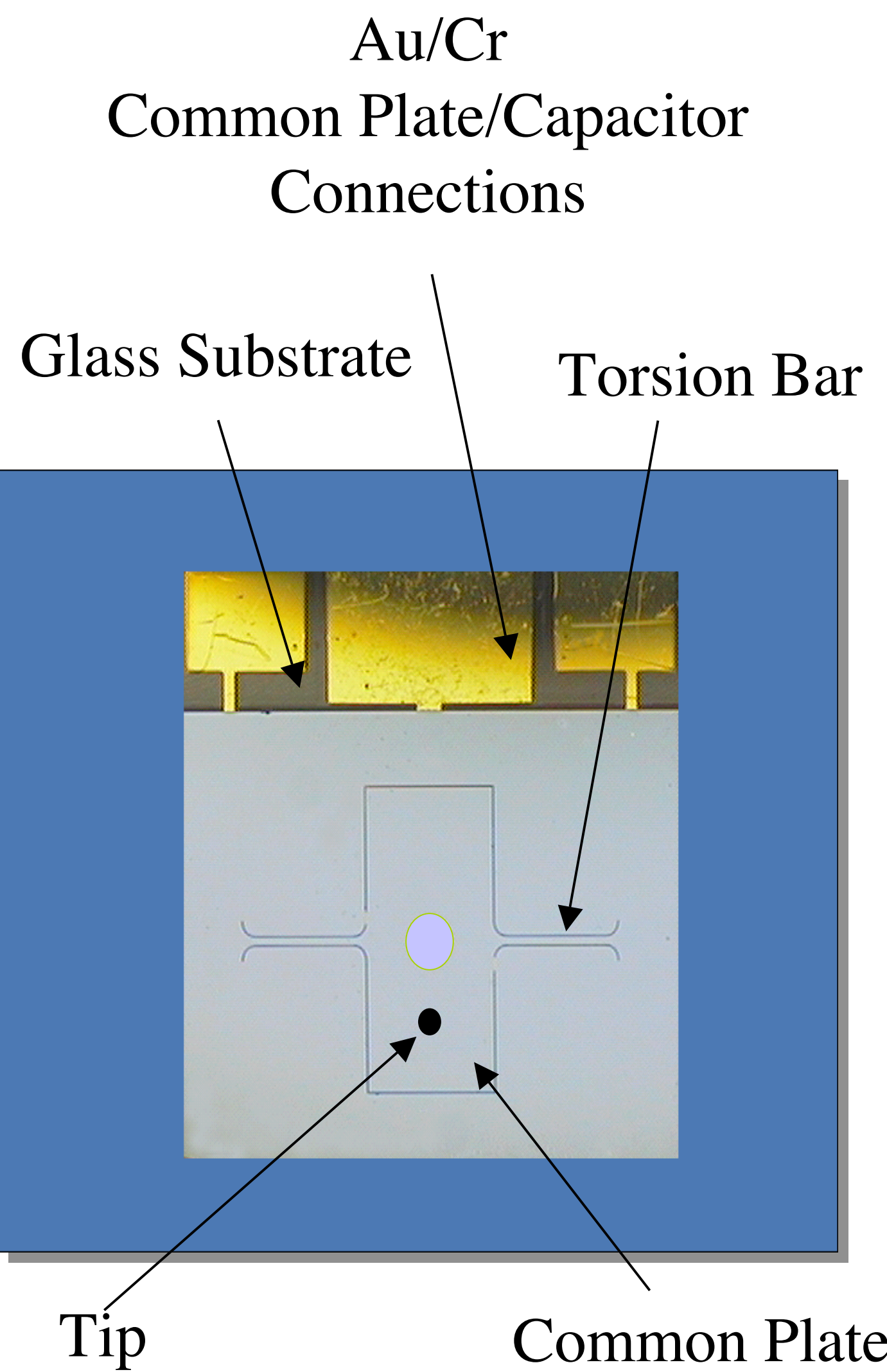
### Modulus Mapping



### The Sensor

- The common plate of a differential capacitor and torsion-bar suspension system is defined by a 25  $\mu\text{m}$  trench Bosch® etched into a 100  $\mu\text{m}$  Si(001) wafer
- The  $\sim 5 \mu\text{m}$  capacitor gap is etched into a Pyrex® wafer and the Au/Cr electrodes are deposited in the gap

These two are then anodically bonded to form the sensor



### Advantages

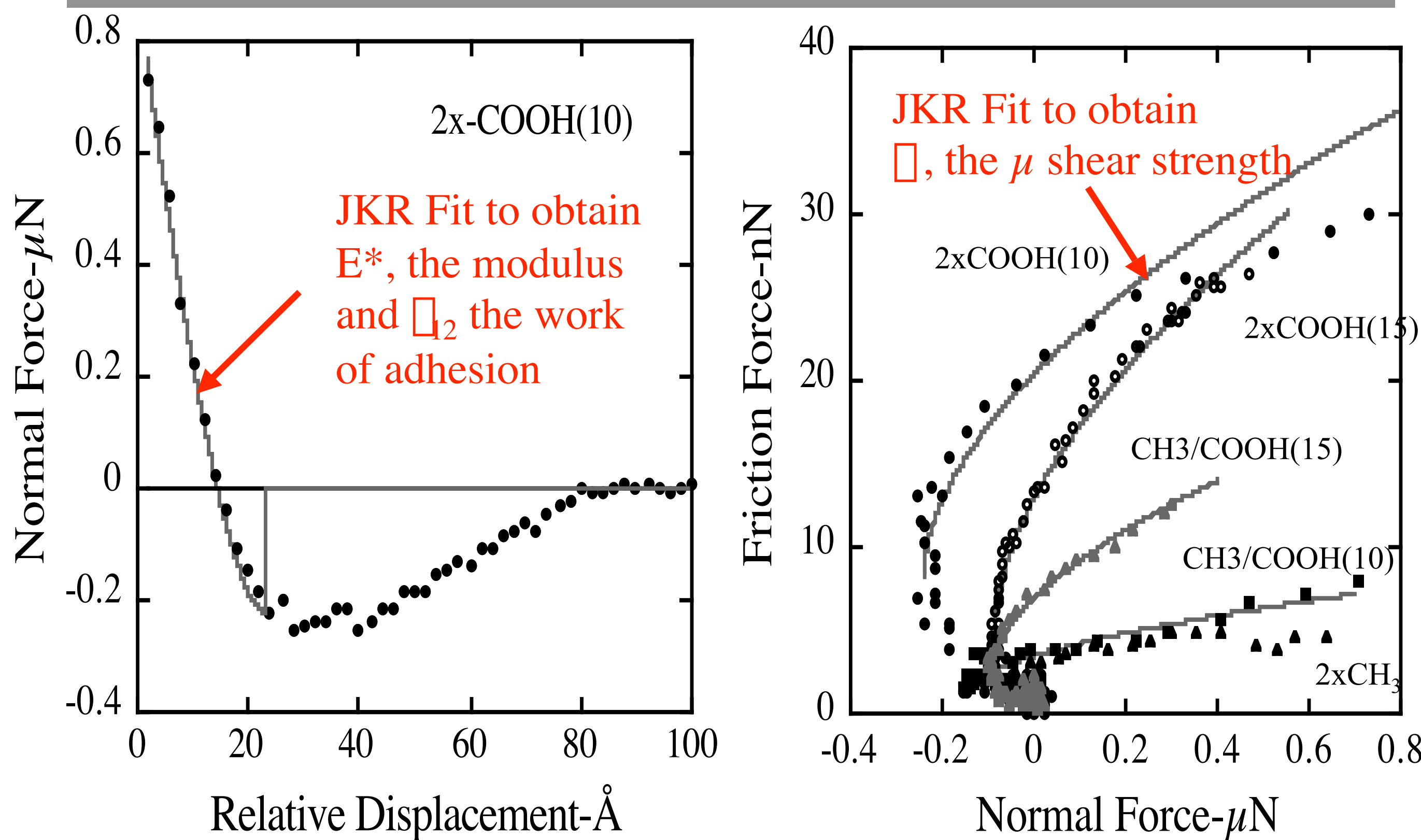
- Quantitative
- Mechanically Stable: measures entire force profile
- Zero Compliance: no energy stored during measurement
- Measure both normal and lateral (friction) forces

### One Example

#### Separating Mechanical & Adhesive Friction

- Both tip and substrate functionalized with  $-\text{CH}_3$  or  $-\text{COOH}$  end groups on SAM films of various lengths
- Data taken of both  $F_n$  vs.  $d$  and  $F_\mu$  vs.  $F_n$
- Results fit with simple contact-mechanics model (JKR) to obtain quantitative values of mechanical and adhesive components of  $\mu$

### JKR Fits: Adhesion, Friction & Nanomechanics



### Friction Shear Strength: Mechanical & Bonding

End Groups	$E^*$ -MPa Total	$E^*$ -MPa Mechanical	$E^*$ -MPa Bonding	Notes
2xCOOH(10)	6.5	2.2	4.3	Two short films Strong inter-film bonds
2xCOOH(15)	3.2	0.8	2.4	Two long films Double intra-film bonds
CH3(15)/COOH(15)	1.6	0.8	0.8	Two long films Single intra-film bonds
CH3(15)/COOH(10)	1.5	1.1	0.4	One short one long film No Chemical bonds
2xCH3(15)	0.8	0.8	0.0	Two long films No chemical bonds

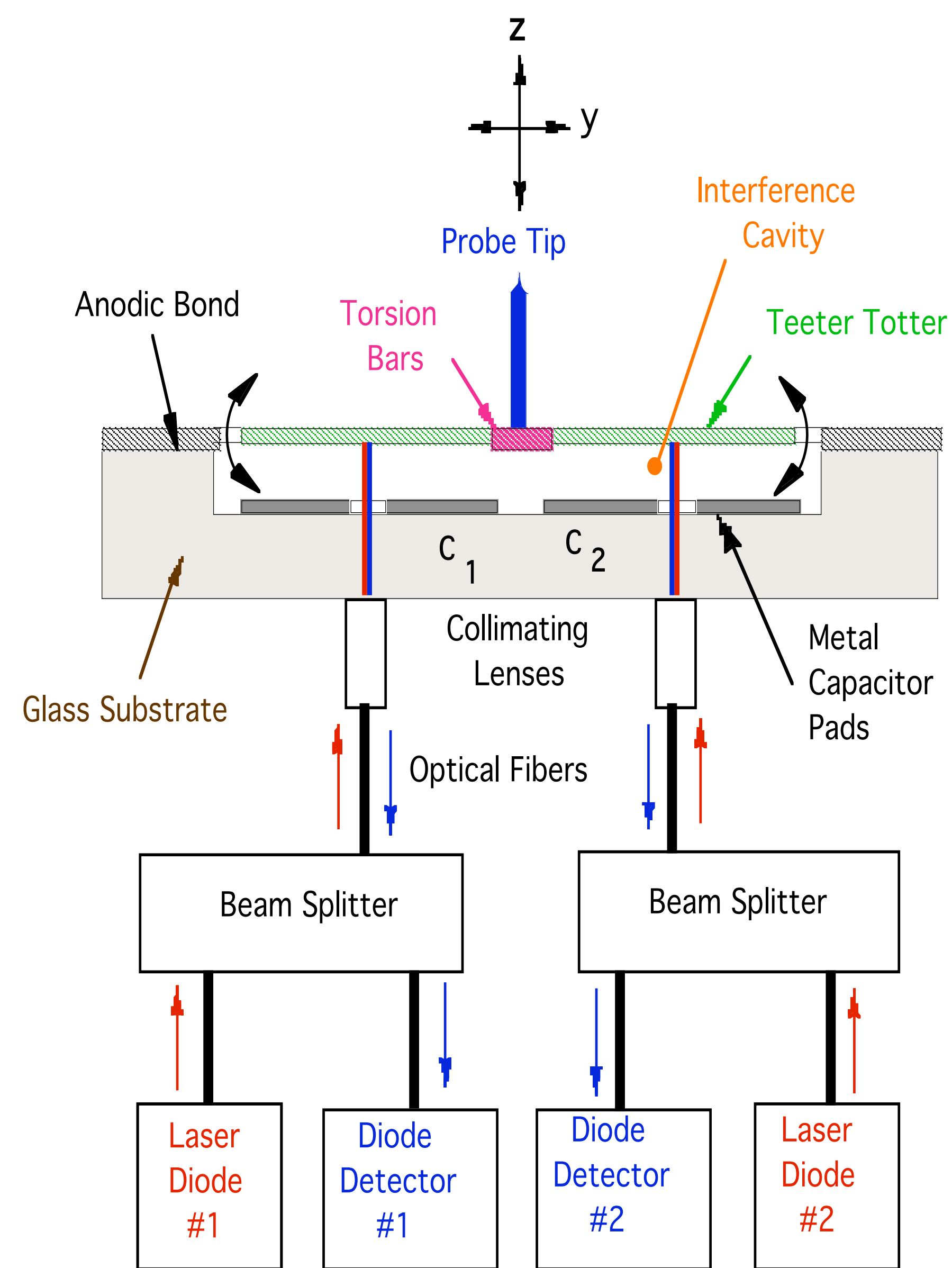
### Conclusions

- While only as accurate as the contact-mechanics model, these are the first quantitative measurements of the mechanical vs. adhesive origins of molecular-level friction and demonstrate:
- Friction from the adhesive interaction results from breaking bonds under lateral tip motion for both inter and intra-film bonds
- Only the even -COOH combination shows inter-film bonding
- The odd length -COOH terminated SAM is virtually hydrophobic
- The strength of inter- is greater than that for the intra-film bonding
- Because of the strain effect, the “modulus” value varies inversely as length

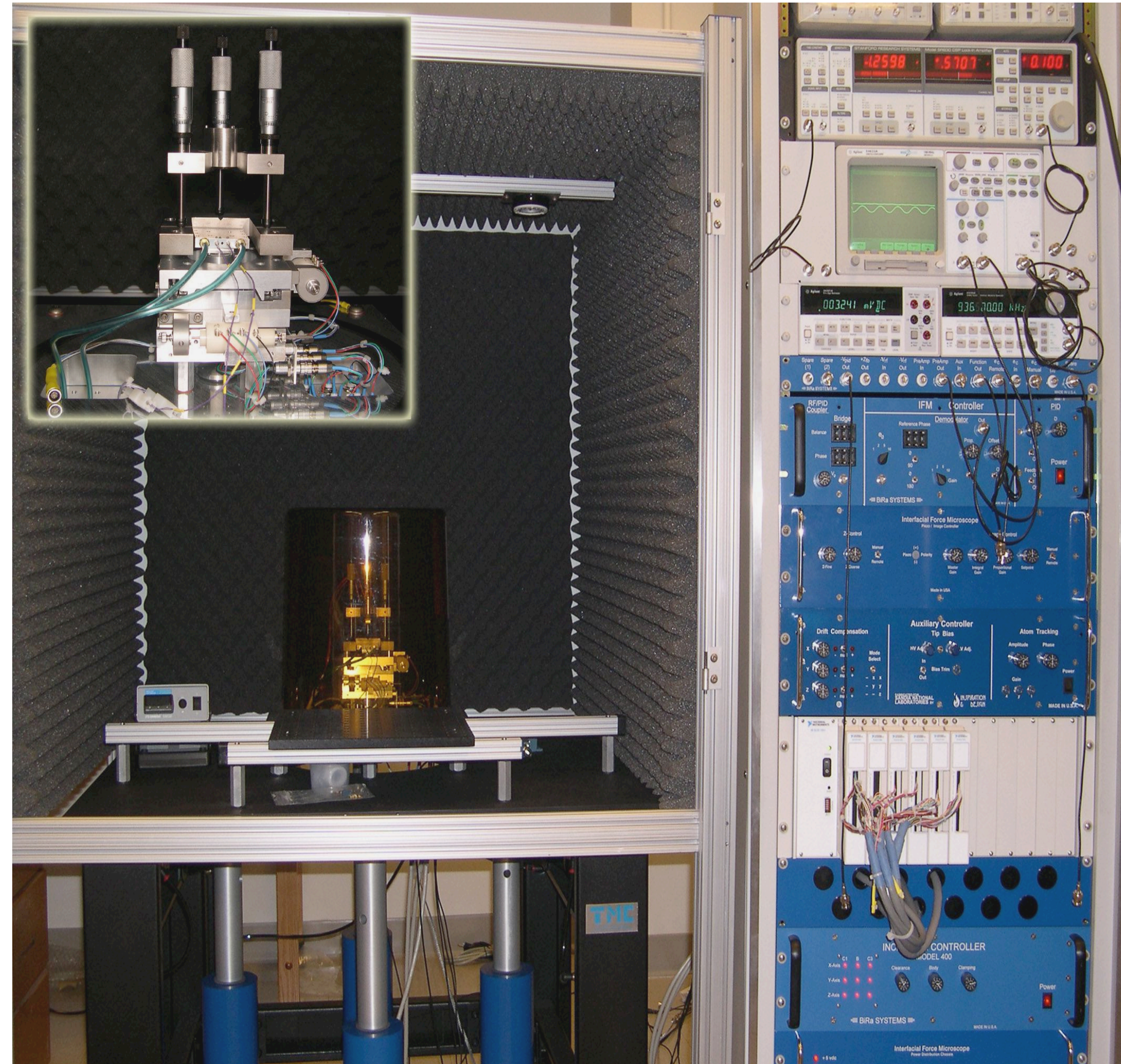
## IFM Instrument Development

### Goal

Develop a fully independent, 2D IFM sensor with laser interferometer-based displacement detection



### The Princeton IFM Instrument



### Instrument Status

- Copyright software under LabView environment (W. L. Smith-Sandia)
- 2D sensor in advanced prototype stage (Patent Pending)
- Hardware available from local vendors
- Currently 14 instruments in use; 6 at Sandia and 8 at various universities

### Collaborators

- W. L. Smith, Sandia: Instrument and software development
- B. C. Bunker, Sandia: Bio-system interactions with tailored surfaces
- J. T. Brinker, Sandia: Fabrication and properties of super-hydrophobic surfaces
- L. Minier, Sandia: Interphase properties and aging in energetic materials
- Prof. X.-Y. Zhu, U. Minnesota: MEMS-level lubrication; friction, wear and stability
- Prof. K. T. Vanderlick, Princeton University: SAM films; structure, adhesion and friction
- Prof. G. Scoles, Princeton University: SAM films; structure, adhesion and friction
- Prof. S. T. Picraux, Arizona State University: Controllable surfaces for bio-systems interactions
- Prof. K. M. Liechti, University of Texas at Austin: Nanomecahnical properties of composite materials
- Prof. R. M. Winter, South Dakota School of Mines: Nanomechanics of interphase materials
- Prof. P. R. Norton, University of Western Ontario: Properties of anti-wear additives